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THE EFFECTS OF WALL SURFACE DEFECTS ON BOUNDARY-LAYER TRANSITION IN QUIET AND NOISY SUPERSONIC FLOW

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INTRODUCTION

The design of supersonic vehicles with laminar-flow control and vehicles such as the Space Shuttle requires information on allowable transition tolerances to fabrication defects such as discrete surface roughness and waviness. The existing data base for the effect of waviness on transition consists primarily of the World War II data of Fage,[1] the studies of Carmichael[2] for the X-21 program, and the lone supersonic work of Howard and Czarnecki[3] in the early 60's. A relatively large data base on the effects of discrete roughness on transition exists for subsonic and supersonic speeds. The existing supersonic wind-tunnel transition data are "contaminated" by wind-tunnel noise emanating from the turbulent boundary layers on the nozzle walls. The present paper will compare roughness and waviness transition data obtained in a "quiet" Mach 3.5 supersonic wind tunnel (Langley Research Center's Supersonic Low-Disturbance Pilot Tunnel[4]) with those obtained in conventional "noisy" flows. See figure 1.

- WAVINESS AND ROUGHNESS CRITERIA REQUIRED FOR $M > 1$ LFC
  - E^N APPROACH ONLY VALID FOR NEGLIGIBLE ROUGHNESS/WAVINESS
  - WHAT IS DEFINITION OF NEGLIGIBLE?
- ONLY ONE WAVINESS $M > 1$ STUDY AVAILABLE AND IS IN A "NOISY" GROUND FACILITY
- ALL ROUGHNESS ($M > 1$, GROUND FACILITY) STUDIES IN NOISY FACILITIES
- PRESENT PAPER:
  - CONDUCTED WITH AND WITHOUT FACILITY NOISE
  - COVERS RELATIVELY WIDE RANGE OF WAVE PARAMETERS
  - INCLUDES INITIAL STUDIES OF ROUGHNESS VS. WAVE EFFECTS

Figure 1

WAVY WALL CONE MODELS

The models used in this study were all 5° half-angle sharp cones with surface finishes better than 5 μ-in. rms and tip diameters less than 0.002 inches. A smooth wall cone instrumented with thermocouples along two rays, 180° apart, was used for comparison with the wavy wall cone data and for the tests with discrete roughness. The surface profiles of the 8 wavy wall cones are shown with exagerated vertical scales. The wavelengths were chosen to fall into the range of the most amplified Tollmein-Schlichting waves for flow over sharp tip smooth cones at the present tunnel operating conditions. For all wavy cones, the waves start 2-inches from the tip of the model and extend to the rear of the 15-inch long cones (figure 2).

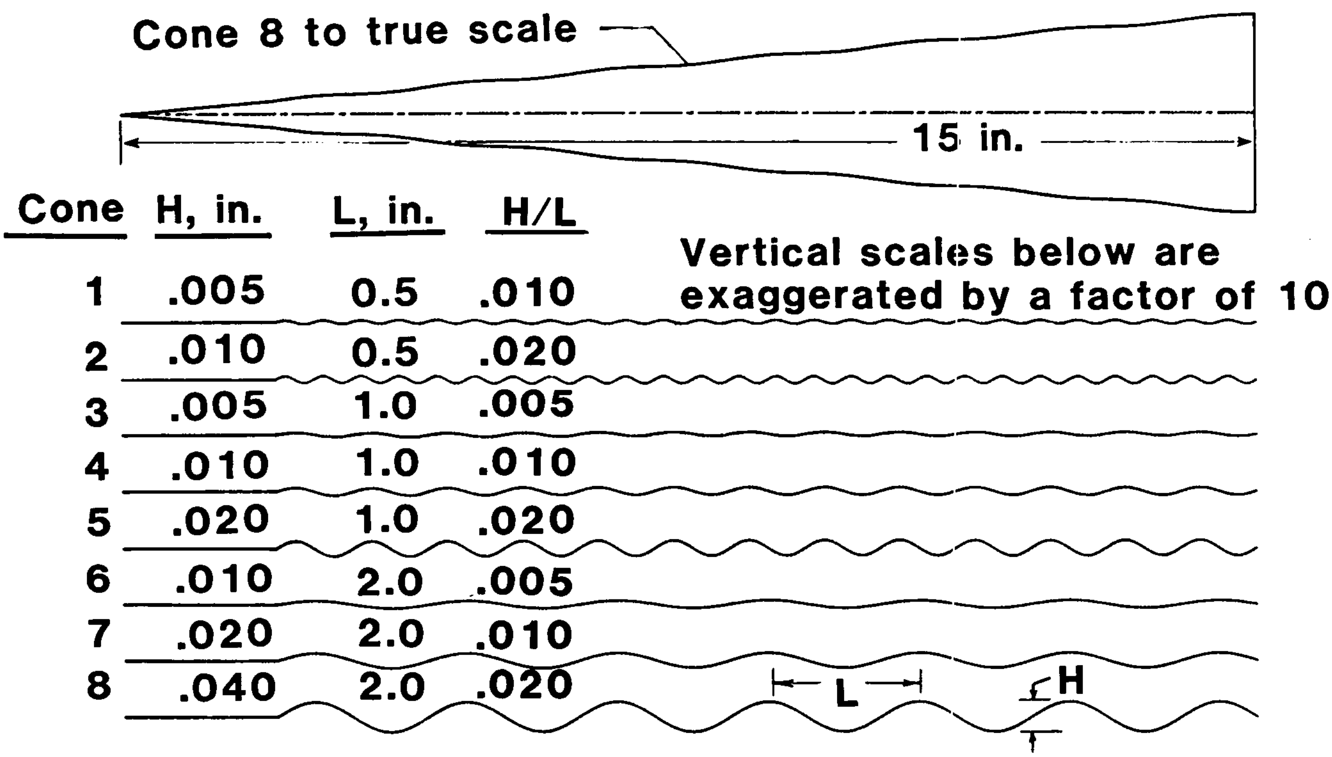


Figure 2

CONE PRESSURE AND PRESSURE GRADIENT DISTRIBUTIONS

Figure 3 shows the surface profiles of the 8 wavy wall cones along with the non-dimensionalized pressures and the pressure gradients calculated from supersonic small disturbance theory. Each of the scales shown applies to the plots for each of the eight cones. The minimiums and maximums in pressure are functions of H/L; the maximums and minimums in pressure gradient are proportional to H/L^2. Cone 2 is seen to have the most severe pressure gradients and cone 6 the mildest gradients. While there is a step increase in pressure at the start of the waves, the pressure rise for the worst case corresponds to the pressure rise of only a 3-degree turn.

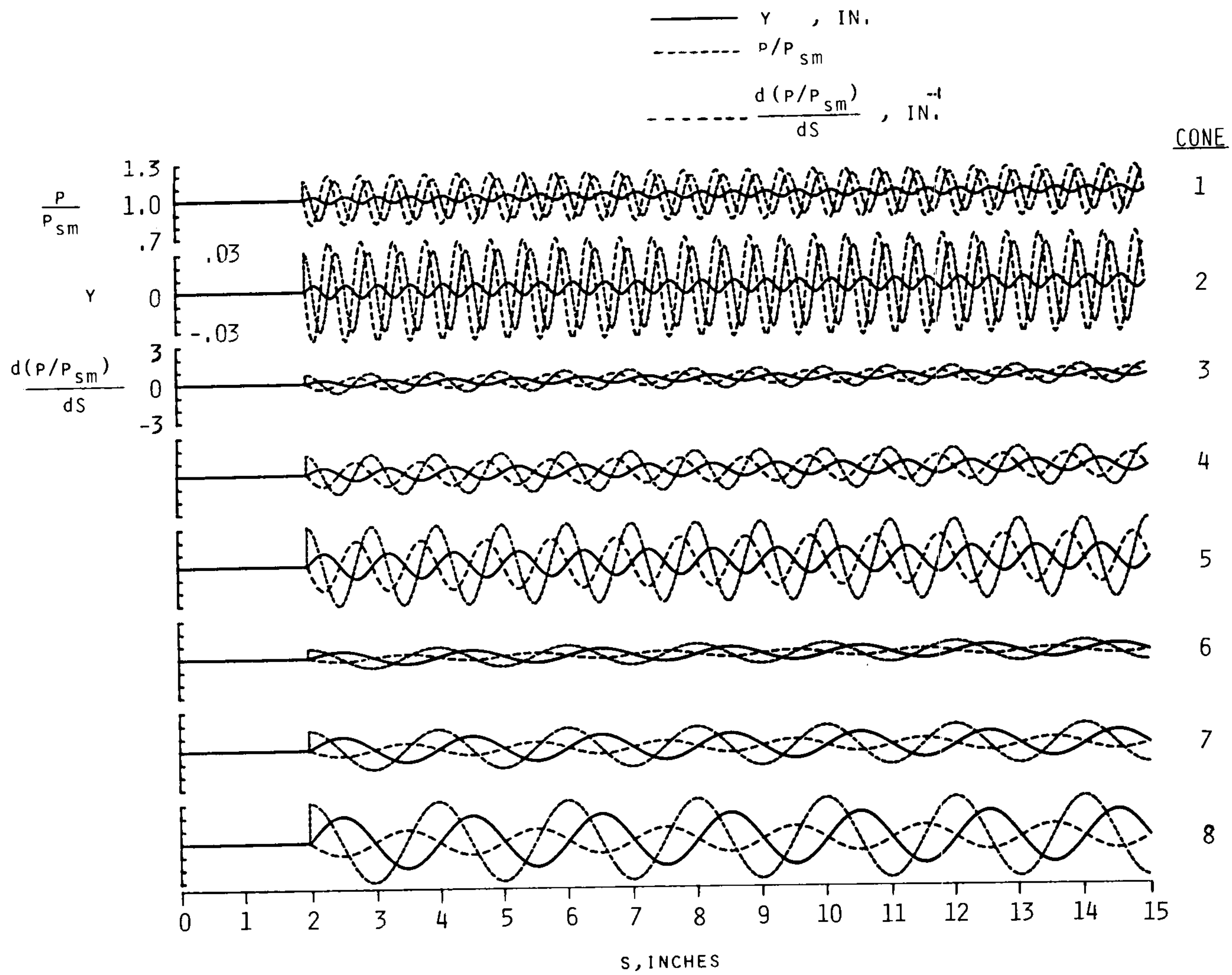


Figure 3

TRANSITION DETECTION TECHNIQUES

Transition on the wavy cones was obtained by using a fixed surface pitot tube and increasing the tunnel total pressure until transition was detected. Figure 4 shows typical variations of the pitot pressure for various pitot positions along the cone surface. In all cases the pitot tube was located at the peak of a wave and no effort was made to determine the patterns of transition movement between peaks. The location of transition was taken at the value of total pressure where there was a sharp increase in pitot pressure. Transition on the smooth cone was determined with recovery temperature distributions measured with thermocouples as well as with pitot tube data. Transition for the recovery temperature distribution was taken at the location of sudden increase in recovery temperature. The recovery temperature and pitot tube techniques gave similar transition Reynolds numbers.

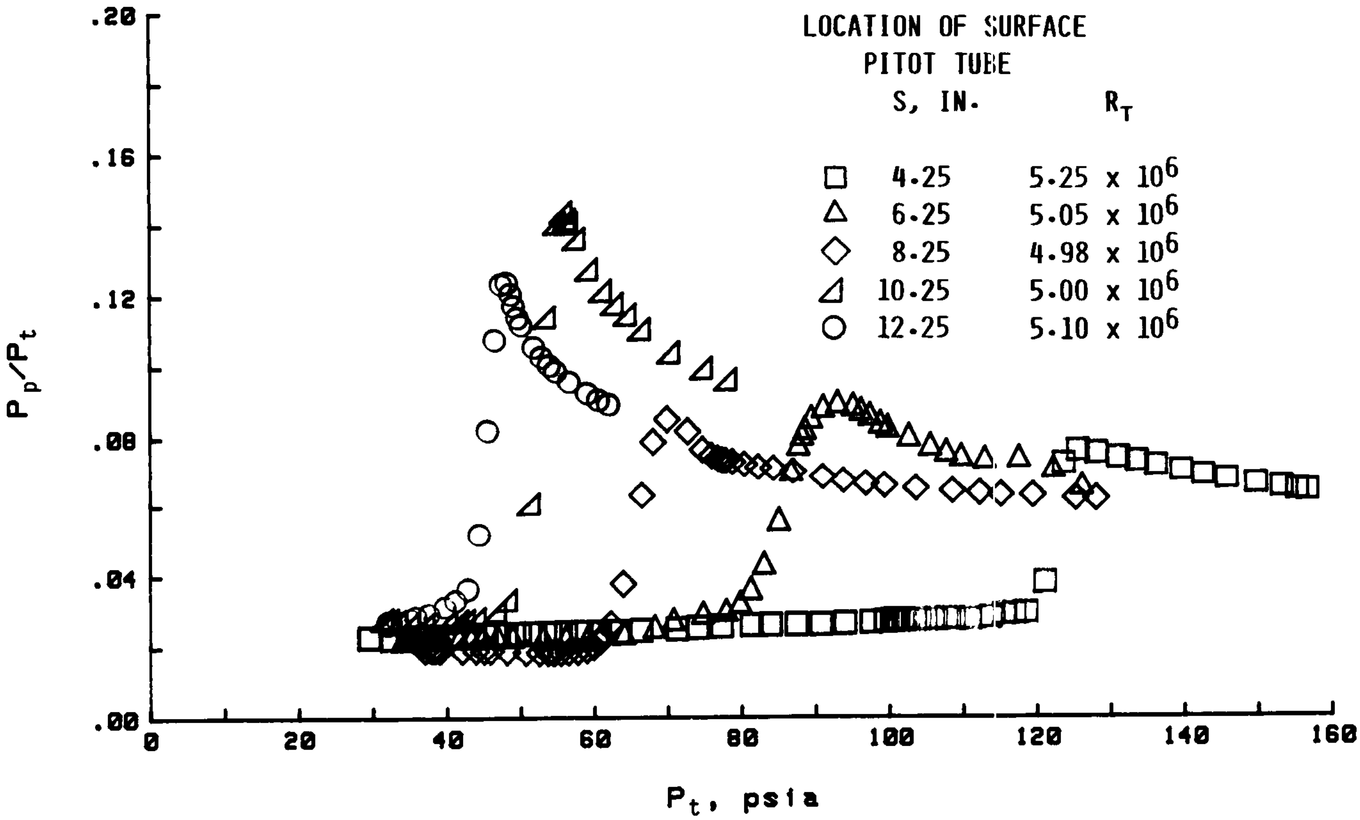


Figure 4

TRANSITION REYNOLDS NUMBERS
WAVY WALL CONES - QUIET FLOW

Figure 5 shows the transition Reynolds numbers as a function of unit Reynolds number for the cones in "quiet flow."[6] The outlined area shows data obtained on smooth cones and the solid line ($R_T = 8 \times 10^6$) is used as a data fairing for comparison with the wavy wall cone data. The waves on all of the cones cause a reduction in transition Reynolds number. In general the data follow the trend of the smooth cone data but at a lower level. At the higher unit Reynolds numbers it is expected that wavy wall cone data would approach the smooth wall data since the smooth wall transition locations are approaching the location of the start of the waves on the wavy wall cones.

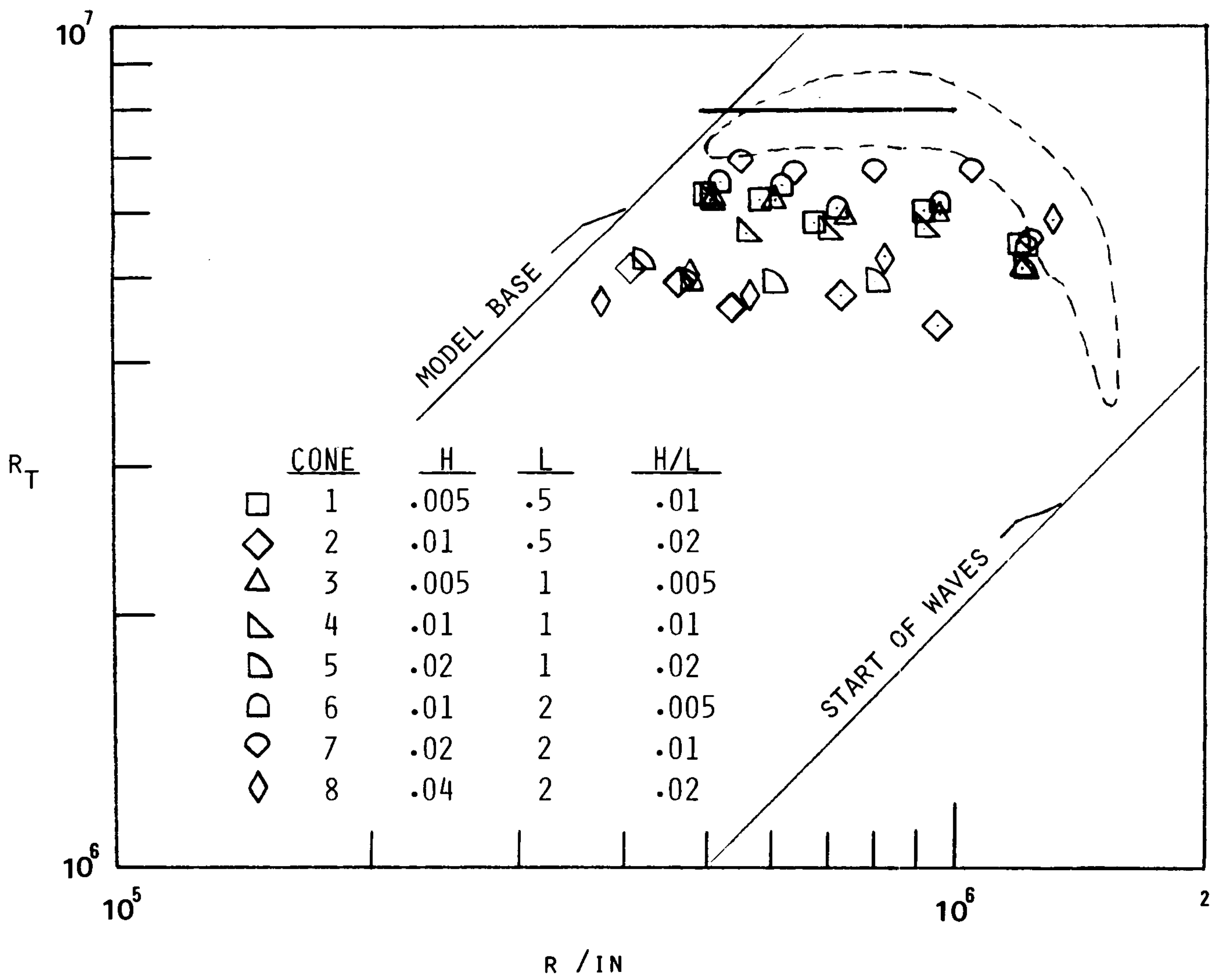


Figure 5

TRANSITION REYNOLDS NUMBERS
WAVY WALL CONES - NOISY FLOW

Figure 6 shows the transition Reynolds numbers for data obtained in a "noisy" flow. The data trends are similar to those of the "quiet" flow data (figure 5) but at much lower levels. The wavy wall cone data merge with the smooth wall data above a unit Reynolds number of 5 x 10^5 per inch where a peak in free-stream noise[4] causes a rapid forward movement in transition location on all of the models.

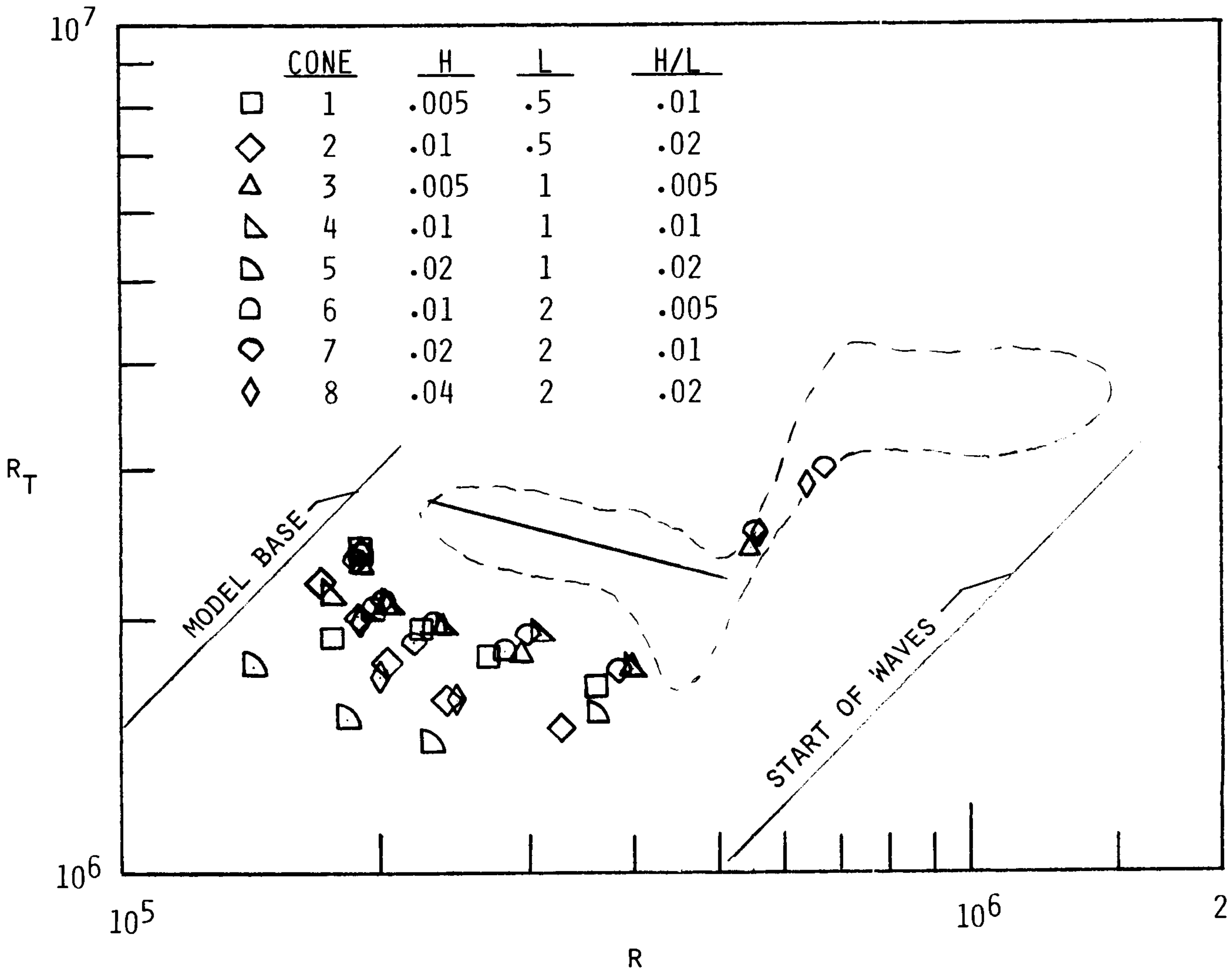
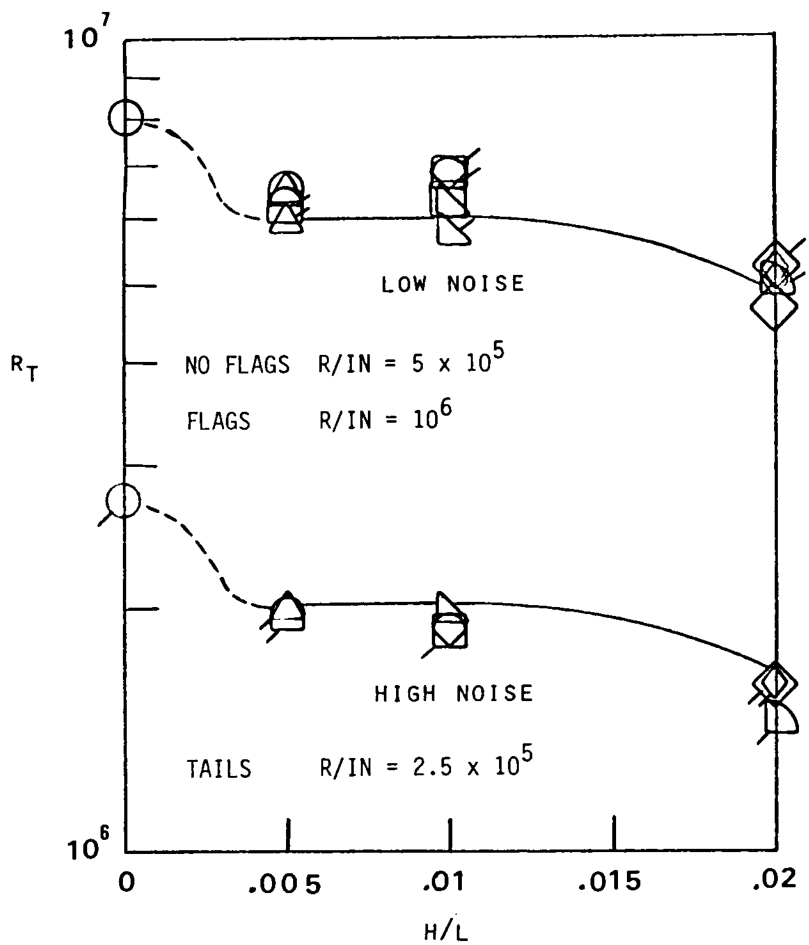


Figure 6

TRANSITION REYNOLDS NUMBERS AS A FUNCTION OF H/L

To better show the effects of the waves, the transition Reynolds numbers are plotted as a function of H/L for constant values of unit Reynolds number. Data for two unit Reynolds numbers in "quiet" flow and one in "noisy" flow are plotted from fairings of the data of figures 5 and 6. Figure 7 shows that the change in transition Reynolds number is primarily a function of H/L. The height of the waves and the number of waves seem to have no obvious effect on the present transition Reynolds number data.



	CONE	H, IN.	L, IN.	H/L
□	1	.005	.5	.01
◇	2	.01	.5	.02
△	3	.005	1	.005
◺	4	.01	1	.01
D	5	.02	1	.02
⌓	6	.01	2	.005
♀	7	.02	2	.01
◊	8	.04	2	.02

Figure 7

PERCENTAGE CHANGE IN TRANSITION POSITION
AS A FUNCTION OF H/L
QUIET FLOW

The "quiet" flow data of figure 7 are plotted in figure 8 in the form of transition distances normalized by the smooth cone transition distances, thus showing the percentage change in transition location as a function of H/L ratio.

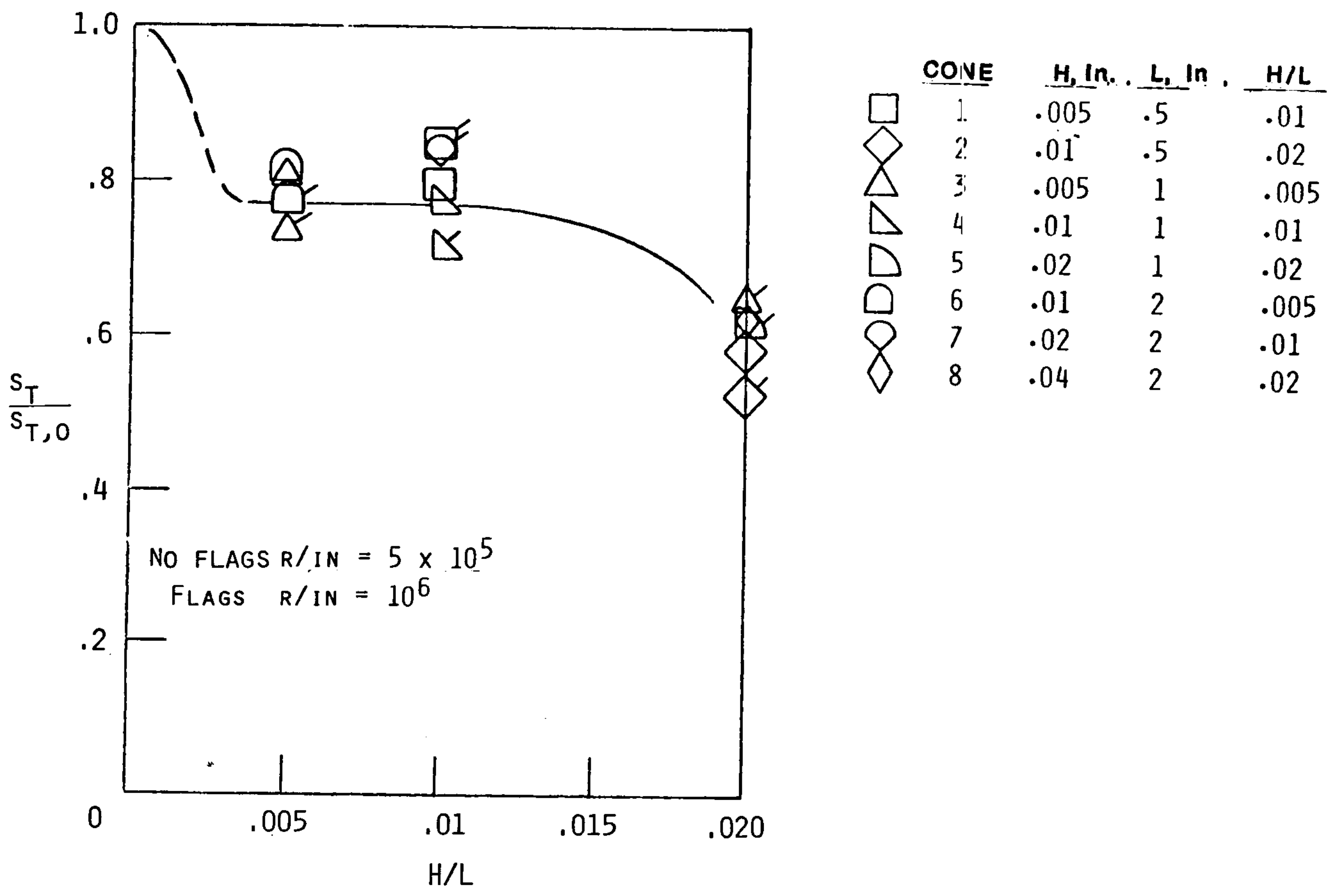
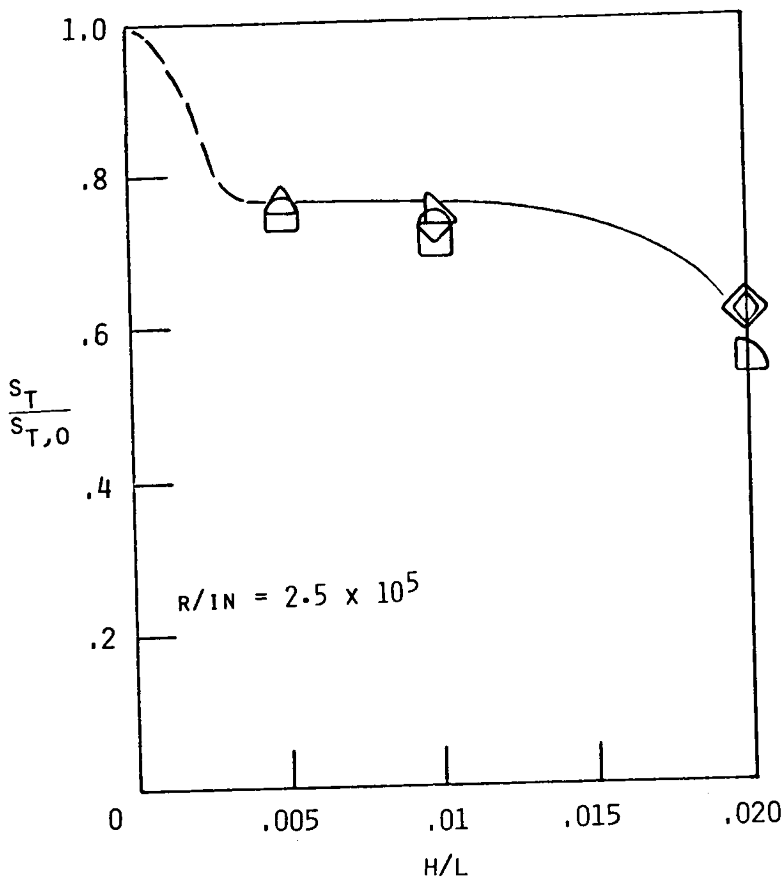


Figure 8

PERCENTAGE CHANGE IN TRANSITION POSITION
AS A FUNCTION OF H/L
NOISY FLOW

Figure 9 shows the "noisy" flow data of figure 7 plotted in the form of transition distances normalized by the smooth cone transition distances. A comparison of figures 8 and 9 indicates that a given H/L causes approximately the same percentage change in transition for both quiet and noisy flows. This result offers hope that trends in data obtained in conventional wind tunnels may be usable.



CONE	H, IN.	L, IN.	H/L
1	.005	.5	.01
2	.01	.5	.02
3	.005	1	.005
4	.01	1	.01
5	.02	1	.02
6	.01	2	.005
7	.02	2	.01
8	.04	2	.02

Figure 9

TRANSITION POSITION ON SMOOTH CONE

Figure 10 shows the transition position on the smooth cone as a function of unit Reynolds number for both quiet and noisy flows. The upper limit to the data is the length of the cone, while the lower limit is determined by the maximum unit Reynolds number in the quiet flow and the start of the instrumentation on the cone for the noisy flow. The regional transition reversal at a unit Reynolds number of about 5×10^5 in the noisy flow is caused by a peak in radiated noise in the nozzle.

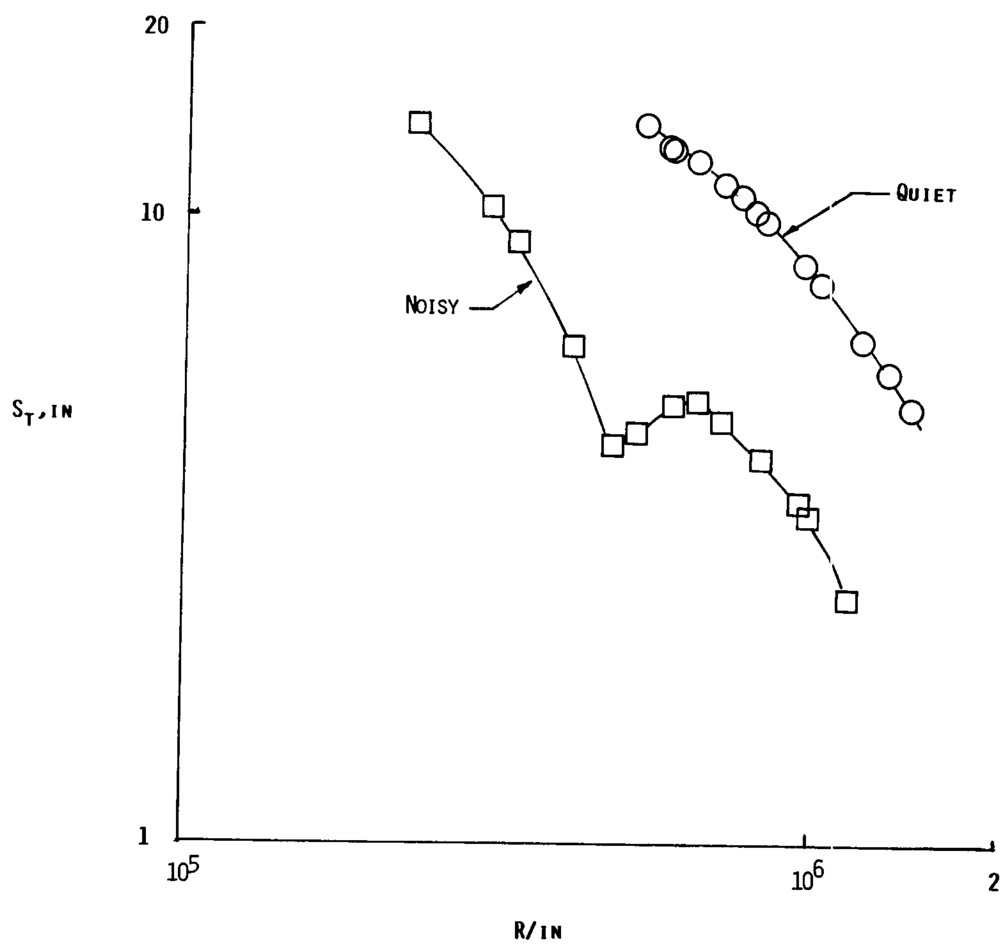


Figure 10

TRANSITION ON CONE WITH ROUGHNESS PARAMETER DEFINITIONS

Figure 11 shows a typical effect of discrete three-dimensional roughness (spheres) on transition position. As the unit Reynolds number is increased, the transition position follows the smooth cone value until at some value of Reynolds number there is a sudden forward movement of the transition position. This unit Reynolds number and height of the roughness determine the critical roughness Reynolds number. Further increases in unit Reynolds number will bring transition close to but at a discrete distance from the roughness. The value at which further increases in unit Reynolds number cause no significant further forward movement in transition determines the effective roughness Reynolds number. While vehicle manufacturers are more interested in critical values, the data base is much larger for values of effective roughness Reynolds number which are mainly of interest to the experimentalist for use in tripping the boundary layer on models. For the present study, critical roughness Reynolds numbers can only be obtained for the range of unit Reynolds numbers at which the smooth cone transition data is available while effective values can be determined on the entire unit Reynolds number range.

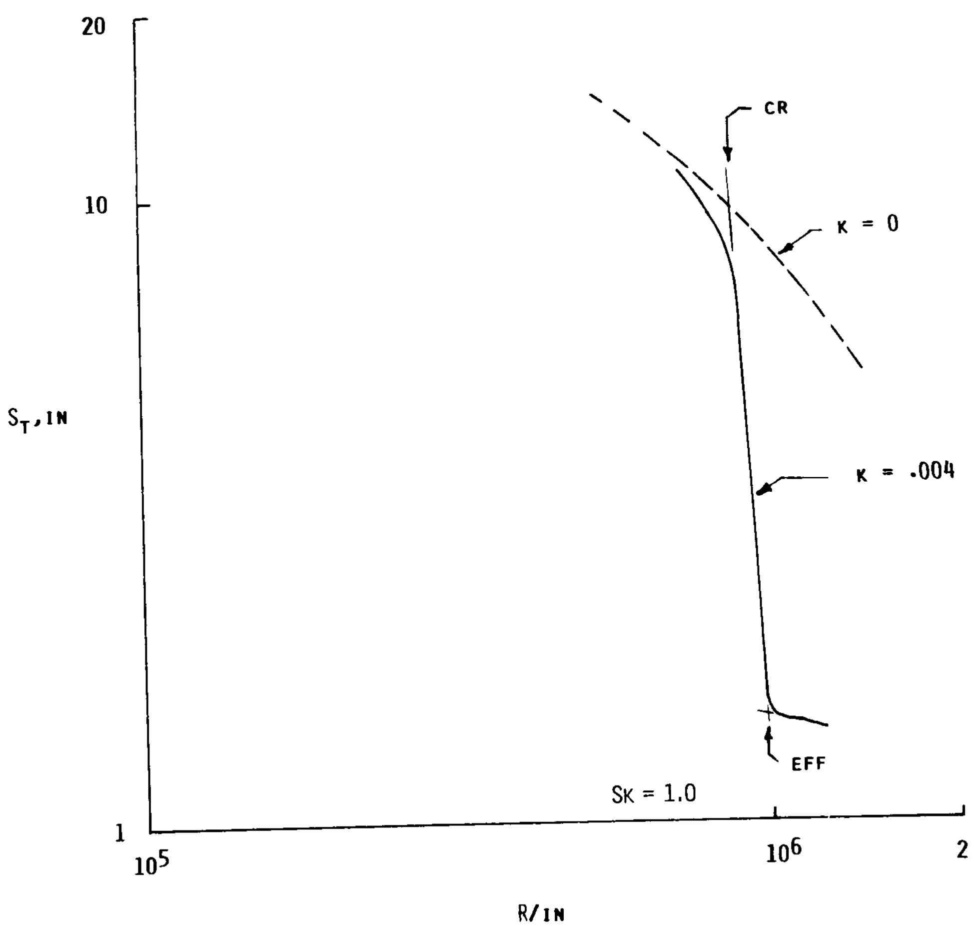


Figure 11

EFFECTIVE ROUGHNESS REYNOLDS NUMBER CORRELATION
VAN DRIEST DATA

Figure 12 shows the data and correlation of Van Driest[5] for effective roughness Reynolds numbers as a function of roughness position Reynolds number on cones. The solid symbols represent the data calculated using the Reynolds number at the edge of the boundary layer ($R_k = k\rho_e u_e/\mu_e$), and the open symbols are the data calculated using the undisturbed conditions inside the boundary layer at the height of the roughness ($r_k = k\rho_k u_k/\mu_k$). The line $r_k = 600$ is a widely used value of effective roughness Reynolds number for subsonic to low supersonic speeds. The solid lines are Van Driest's correlation for cones:

$$R_{k,eff} = 32.8 \left(1 + \frac{\gamma - 1}{2} M_e^2\right) R_{S_k}^{.25}$$

and show excellent agreement with the data. The ease of calculation makes the Van Driest correlation the method of choice. The present study falls in the range of Mach numbers covered by Van Driest, and both sets of data were obtained on sharp 10° cones.

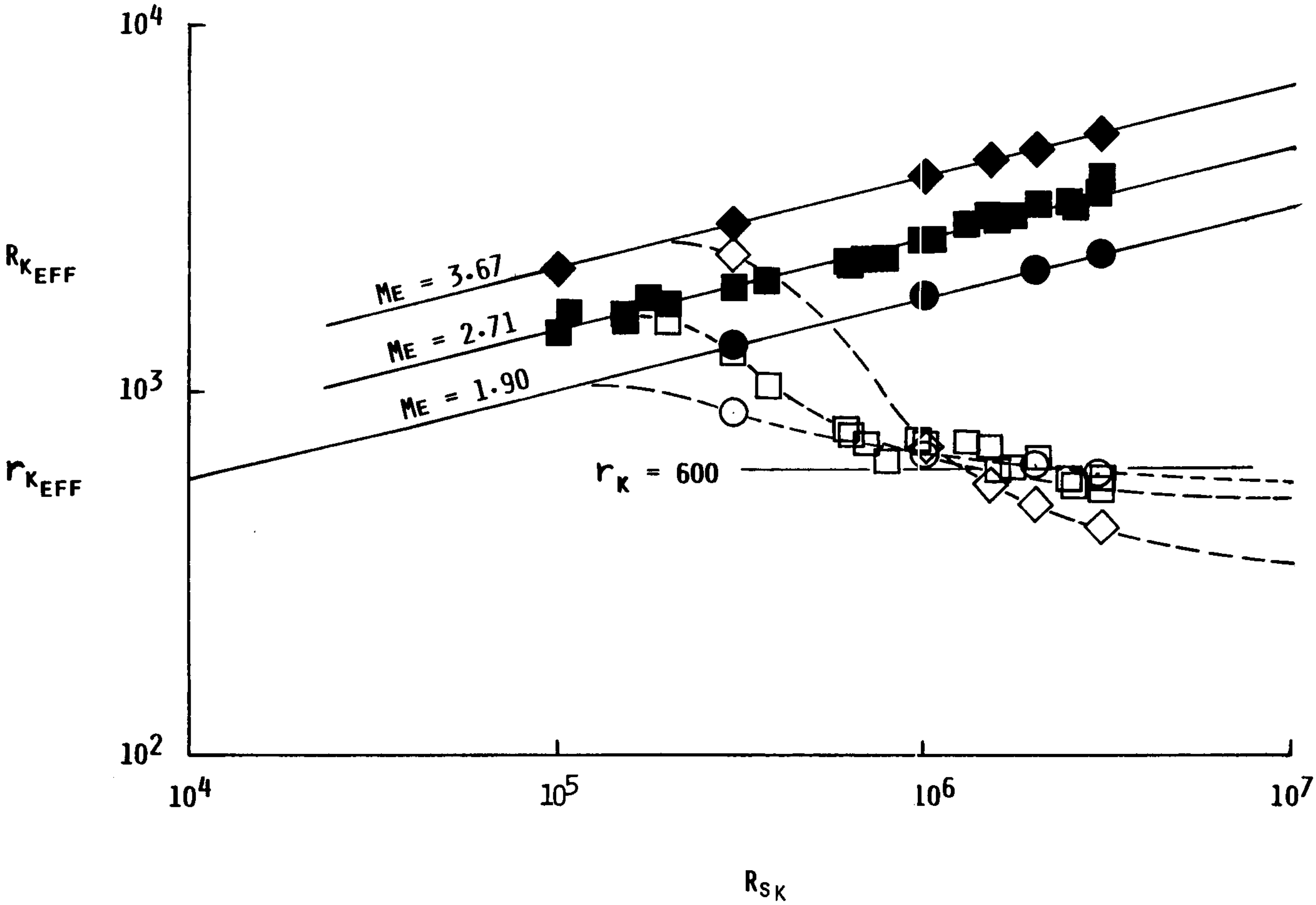


Figure 12

ROUGHNESS REYNOLDS NUMBER CORRELATIONS
QUIET TUNNEL DATA

Figure 13 shows the data of the present study in the form of effective and critical roughness Reynolds numbers as a function of the roughness position Reynolds number. The solid line is the Van Driest correlation for the local cone Mach number, and the dashed lines are fairings of the quiet and noisy effective values. Both quiet and noisy values are above the Van Driest correlation line, but neither shows significant differences. The "quiet" flow data are about 20 percent higher than the correlation and 10 percent higher than the noisy flow data. The few data points for critical values of roughness Reynolds numbers seem to indicate the same percentage difference in quiet and noisy flows and somewhat less influence of position Reynolds number on the value. These very preliminary data indicate that the existing data base may be usable and conservative.

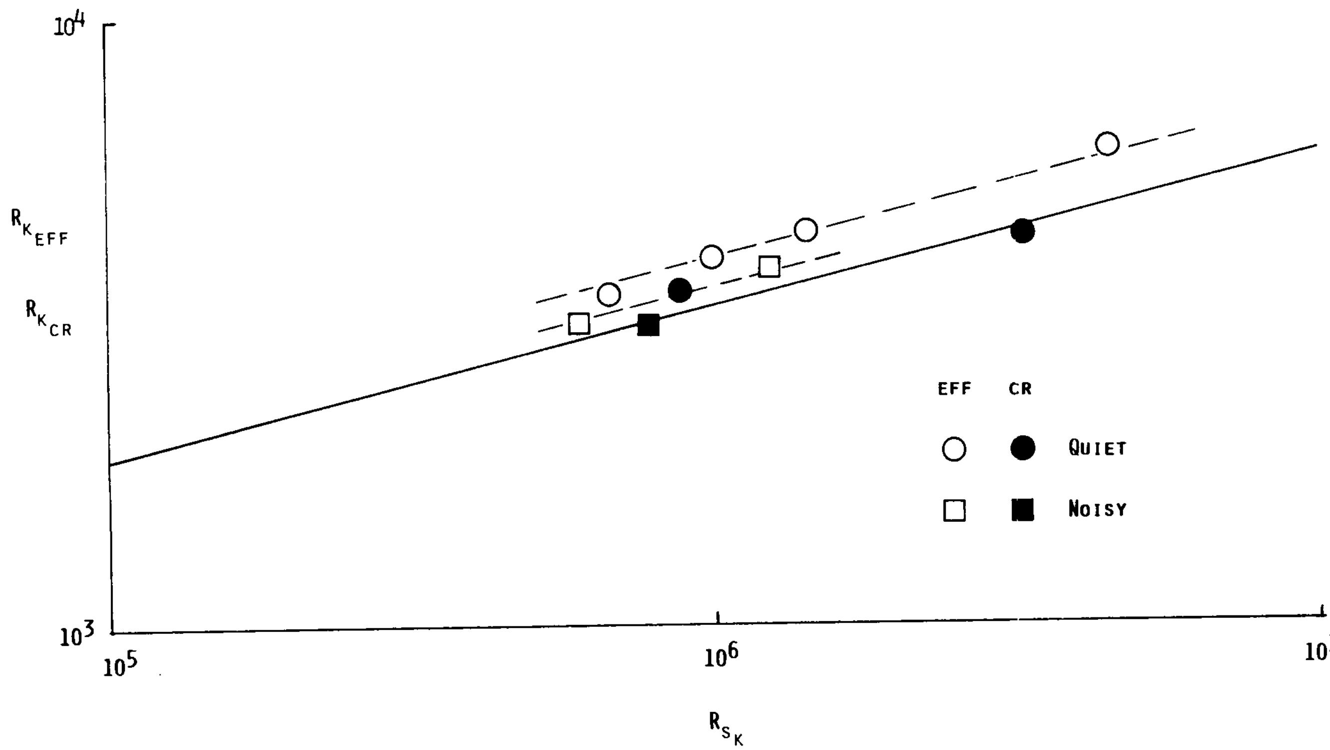


Figure 13

CONCLUSIONS

Waviness

1. Effect of sinusoidal waves on transition is mainly a function of wavelength-to-height ratio - H/L.

2. The effect of waves on transition was much less than a single trip wire of similar height.

3. No waves were found which did not affect transition; no lower critical size was found.

4. A given wave caused the same percentage change in transition in quiet and noisy flows.

Discrete Roughness

1. Effect of noise on effective roughness Reynolds numbers is small (< 20 percent).

2. Effect of noise on critical roughness Reynolds numbers appears small based on very preliminary data.

3. Existing data base may be usable and conservative.

REFERENCES

1. Fage, A.: The Smallest Size of a Spanwise Surface Corrugation Which Affects Boundary-Layer Transition on an Airfoil. Reports and Memoranda No. 2120, British Aeronautical Research Committee, Vol. I, 1943, pp. 261-279.

2. Carmichael, B. H.: Surface Waviness Criteria for Swept and Unswept Laminar Suction Wings. Report No. NOR-59-438 (BLC-123), Northrop Corp, August 1959.

3. Howard, P. W.; and Czarnecki, K. R.: Effect of Fabrication-Type Surface Roughness on Transition on Ogive-Cylinder Models at Mach Numbers of 1.61 and 3.01. NASA TN D-1933, July 1963.

4. Beckwith, I. E.; Creel, T. R., Jr.; Chen, F.-J.; and Kendall, J. M.: Freestream Noise and Transition Measurements on a Cone in a Mach 3.5 Pilot Low-Disturbance Tunnel. NASA TP-2180, September 1983.

5. Van Driest, E. R.; and McCauley, W. D.: The Effect of Controlled Three-Dimensional Roughness on Boundary-Layer Transition at Supersonic Speeds. Journal of Aerospace Sciences, Vol. 27, No. 4, April 1960, pp. 261-271, 303.